

PAPER

Enhancing Preschool English Literacy through Mobile 3D Pyramid Holograms: The PyraRead Study

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ABSTRACT

The literacy issue in preschool language learning has been highlighted worldwide, particularly due to the lack of visualization experiences using three-dimensional (3D) tools. Holograms, as part of current technological trends in education, have emerged as a promising solution. A type of reflective hologram known as the three-dimensional pyramid hologram (3DPH) has the potential to visualize content in a life-like manner, thereby enhancing children's interactions and understanding through meaningful visual experiences. This study aims to examine the effects of a mobile-based 3DPH application called PyraRead (Pyramid for Reading) in enhancing preschool children's English literacy. By delivering interactive 3D holographic content via mobile devices, PyraRead enables flexible and engaging learning experiences beyond traditional classroom tools. This study investigates both children's achievement and their interactions, including their engagement with the mobile PyraRead and with peers. A quasi-experimental design was employed. The results showed that children who used the mobile PyraRead demonstrated improved English literacy, and 12 out of the 15 observed interaction behaviors were positively associated with their learning outcomes. These findings suggest that learning through the mobile PyraRead effectively promotes children's interactions and engagement, ultimately contributing to improvements in their English literacy skills. Although based on a modest sample, the study provides early evidence of the potential of mobile 3DPH tools to enrich preschool literacy learning through immersive and interactive experiences.

KEYWORDS

mobile learning, three-dimensional pyramid hologram (3DPH), preschool literacy, children's achievement, learning interactions

1 INTRODUCTION

Living in a world where technology plays a crucial role, all fields are highly influenced by technology. The field of education will surely benefit by using technology because the innovation in technology provides a positive impact on all levels of education, including early childhood education. Children who start their early

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learning in a fun and enjoyable environment are more likely to engage actively in learning activities. Learning tools with three-dimensional (3D) elements align well with children's level of understanding, spark their motivation, and improve learning performance [1], [2]. The more engagement that occurs during learning, the greater the improvement in children's understanding. As highlighted in previous studies, engaging with 3D tools enhances children's understanding across various subjects, including language learning, by improving vocabulary acquisition [3], [4]. Thus, this statement is strongly supported by the results of a study that indicated that the reading development of five- to six-year-old children reflects their cognitive ability [5].

In a global context, a study emphasized that children who develop strong literacy skills in the early years are better prepared to understand and benefit from advanced materials as they progress in their education [6]. Their study found that 534 of the primary school students who participated were illiterate. The stronger the literacy foundation established in the first year of preschool, the greater the academic success throughout the students' educational journey and the better their readiness for entering primary school, which in turn supports children's cognitive stimulation [7]. In addition to this study, another study raised concerns about illiteracy, highlighting it as a serious issue that indirectly contributes to poverty in a country. Literacy rates, whether low or high, reflect the effectiveness of the primary education system [8]. In the context of Malaysia, approximately 13% of late primary school children were found to be not proficient in reading, and half of 15-year-olds scored below the expected reading level [9]. This issue should be addressed starting from early education to ensure timely intervention. A study by Hussin et al. [10] emphasized that preschool children aged five to six must master early literacy components, such as phonemic awareness and print concepts, to support the development of reading skills. Another study also found that preschool teachers in Malaysia often struggle to teach English effectively due to limited training, inadequate instructional resources, and students' low English proficiency [11].

In recent years, technology-based learning tools that incorporate elements of play have become important in introducing learning concepts to children, supported by global discussions on digital innovation and cloud-based learning technologies that enrich interactive educational experiences [12]. Globally, studies have highlighted that children are more motivated to understand these concepts when engaging with 3D visualization tools, such as augmented reality (AR), particularly in language learning [13], and mobile learning has been increasingly recognized for its accessibility and effectiveness across diverse educational settings [14]. Other studies have agreed that engaging in digital play-based learning fosters greater cognitive and social development [15], [16]. This is where the 3D concept plays a role, as it helps visualize learning subjects in a more realistic and engaging way, thereby ensuring playful learning activities. Nevertheless, several studies found that the materials currently available for preschool children are still largely based on traditional methods. This was supported by findings showing that teachers often provided only a brief overview of a topic through one-way teaching, using 2D games and desktop environments to help students understand the subject, enhance cognition, and improve system responsiveness as well as emotional expressiveness [17], [18]. Therefore, in improving early childhood reading comprehension and literacy, 3D tools have been shown to encourage children to read more effectively, with outcomes reported to be twice as good as learning through traditional methods [19]. Research has shown that interactive experiences can strengthen the effectiveness of 360-degree technology in assessing children's

cognitive abilities [20]. Chuang et al. [21] found that a well-designed 3D visualization tool can improve children's early literacy skills during reading, while Milani et al. [22] noted that using 3D learning tools helps maintain children's attention and supports their reading development. These results are in line with Mayer's Cognitive Theory of Multimedia Learning, which highlights the benefits of presenting information through different channels. They also support constructivist and play-based learning perspectives, which emphasize that children learn best by actively engaging in playful and meaningful activities that stimulate curiosity and deepen literacy skills.

Hologram is an interactive 3D tool that enhances visual learning by projecting realistic and immersive images, making abstract concepts more tangible and engaging for learners. Although introduced more than a decade ago, Jeong's [23] classification of holograms into reflection, transmission, and computer-generated types remains a fundamental reference point for both traditional and modern holographic research. One of the modern holographic tools, the pyramid hologram, is a type of reflection hologram that uses a pyramid prism to project objects in 360-degree views. This technology has proven effective due to its ability to create a 3D display that appears to float in mid-air with a full 360-degree representation of the image [24]. Consequently, children often perceive this 3D holographic display as enchanting and almost magical, producing a 'wow' effect [25], [26]. Moreover, pyramid holograms allow viewers, especially students, to observe objects or subjects from different angles, enabling them to see the same outcome from any viewing position [27], [28]. Mobile pyramid holograms have also shown significant improvements in children's learning. Lubis [29] reported that children in the experimental group demonstrated significantly greater improvement in pronunciation accuracy, particularly with challenging English phonemes. The study further revealed that the use of a 3D holographic mobile application enhanced students' motivation and engagement while reducing pronunciation anxiety in second language learning.

Following a review of the literature, this study identified several research gaps. Although many studies have examined the effectiveness of 3D tools in classroom learning, most international research has focused on higher education or STEM-related subjects such as science, mathematics, and medical training, with far less attention given to early literacy development. Research specifically targeting holographic displays, particularly pyramid holograms, has remained scarce worldwide in the context of preschool English literacy. Moreover, while AR and virtual reality (VR) have been studied globally as interactive learning tools, the use of mobile-based pyramid holograms as an accessible and cost-effective alternative for young learners has not yet been systematically investigated.

This study contributes to addressing both national and international research gaps. It is among the first to examine the potential of mobile 3D Pyramid Hologram (3DPH) technology, through the PyraRead (Pyramid for Reading) application, in supporting preschool children's English literacy by focusing on foundational skills such as spelling, recognition of high-frequency words, and simple phrases. Grounded in global theoretical frameworks such as Piaget's Theory of Cognitive Development, Play-Based Learning Theory, and Mayer's Cognitive Theory of Multimedia Learning, the study extends international discussions on immersive technologies into the early childhood context. The findings therefore provide valuable insights not only for Malaysia but also contribute to ongoing international discourse on immersive technologies in early literacy, addressing the existing research gap in preschool holographic learning tools. To address these gaps, this study formulated the following

research questions to investigate the effectiveness of the mobile 3DPH tool, PyraRead, on children's English literacy development.

1. What are the effects of the 3D mobile PyraRead on preschool children's achievement in enhancing their English literacy compared to the 2D mobile video?
2. What are the children's interactions when engaging with the 3D mobile PyraRead, in terms of their interactions with the tool and with peers?
3. What is the relationship between preschool children's achievement and their interactions when using the 3D mobile PyraRead to improve their English literacy?

2 METHODS

2.1 Participants

Fifty 6-year-old preschool children from two government preschools located in the Johor state of Malaysia participated in the study, selected through convenience sampling. Two different preschool classes were assigned as the experimental group (learning English via the 3D mobile PyraRead app) and the control group (learning English via a 2D mobile video). Each group consisted of 25 preschoolers. The learning content for both applications was identical, following the Malaysian National Preschool Curriculum Standard (NPCS) for English. During the study, the children were seated in small groups and used the same type of mobile device, which were tablets with 10-inch screens. The selection of only two preschools was based on accessibility, administrative approval, and consistency in curriculum implementation within the same educational district. While this focused geographic scope provided a controlled and uniform learning environment, it may also limit the generalizability of findings to other regions or preschool contexts. This study was conducted with ethical approval from the Ministry of Education, Malaysia (Ref. No.: KPM.600-3/2/3-eras (4505)), and all necessary permissions and parental consents were obtained prior to data collection.

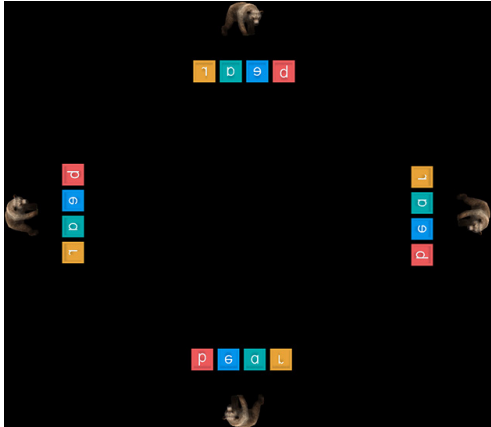
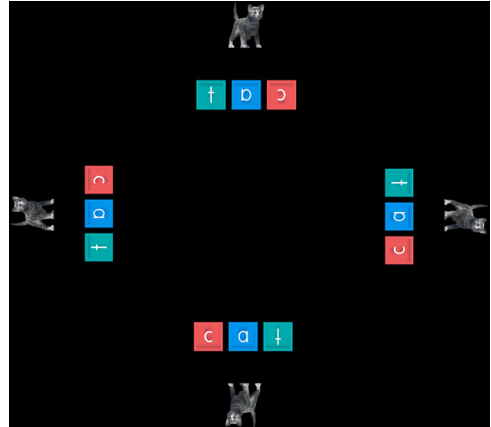
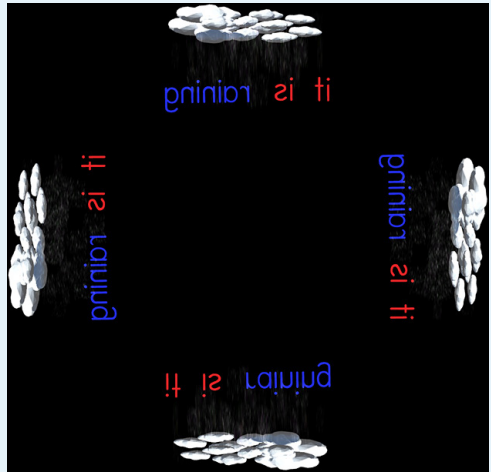
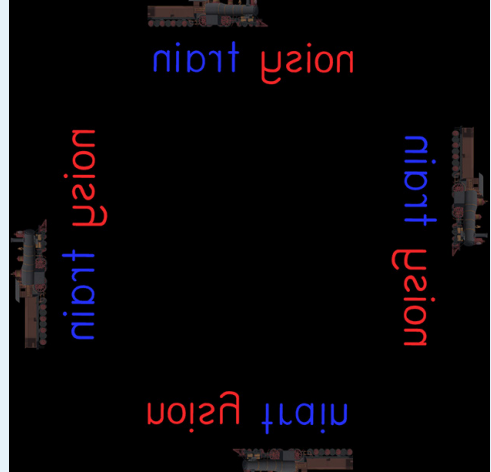
2.2 Instruments

In this study, three instruments were used: mobile PyraRead as the classroom learning tool, pre-test and post-test to assess the preschool children's achievement in English literacy, and an interaction checklist to examine their interactions with the tool and their peers during the mobile PyraRead activity.

The main instrument, PyraRead, a 3D mobile application, was designed in accordance with the NPCS through its four sub-apps. Its development also adhered to Mayer's Cognitive Theory of Multimedia Learning [30], ensuring alignment with Mayer's principles. In addition, Piaget's Theory of Cognitive Development [31] guided the design to reflect the pre-operational stage of children's cognition, particularly assimilation and accommodation. Finally, the characteristics of play outlined by the National Council for Curriculum and Assessment (NCCA) [32], which emphasize that play should be voluntary, meaningful, low-risk, spontaneous, symbolic, sociable, and enjoyable, were incorporated to ensure that PyraRead supports a play-based learning environment for preschool children learning English. Specifically, the first sub-app features animated 3D models of animals representing the 26 letters of the alphabet. The second sub-app focuses on nouns (animals and objects)

organized according to rhymes (-at, -en, -ip, -og) of single-syllable words. The third sub-app introduces nouns (objects and verbs) to form simple sentences using suggested high-frequency words (e.g., I, am, it, is, they, are, he, has, a). The fourth sub-app emphasizes constructing simple phrases using adjective–noun combinations. Notably, all the animated objects in PyraRead are rendered in 3D. Examples of the content are illustrated in the figures presented in Table 1.

Table 1. Mobile PyraRead content based on respective sub-apps

Sub-Apps 1: Alphabet Sound	Sub-Apps 2: Recognize Syllables
	
Sub-Apps 3: Enjoy Reading	Sub-Apps 4: Amazing Phrases
	

Pre- and post-test assessments were used to examine the effects of the mobile PyraRead application on children’s achievement. In simple terms, during classroom learning, children using PyraRead are expected to gain a better understanding of English compared to those using a 2D mobile video, due to the enhanced visual display. The tests were developed based on several considerations: the total number of questions did not exceed 20, the maximum number of pictures per page was four, the font used was Syazalina83v3, and the font size was 18 points [33], [34]. Specifically, the test questions were developed in alignment with Piaget’s Theory of Cognitive Development, which outlines two main cognitive processes during the pre-operational stage: assimilation and accommodation. Briefly defined, assimilation is

the process of using existing schemas to understand new information, while accommodation involves restructuring existing schemas to adapt to new information. In this study, these two processes guided the development of pre- and post-test items. When the test content was similar to that of the 3D mobile PyraRead or 2D mobile video, the children engaged in assimilation, using their existing knowledge to answer the questions. However, when presented with content that differed from their prior understanding, children had to apply accommodation by modifying or restructuring their schemas to choose the correct answers. Both assimilation and accommodation are crucial for the development of children's cognitive and language abilities, as demonstrated when they successfully answered the questions.

Children's interactions with the learning tool and their peers were assessed by adapting a checklist from Cheng and Tsai [35]. These interactions were categorized into three major behaviors with corresponding codes: (1) children's interaction with the content of PyraRead (CIC), (2) children's interaction with the 3D elements of PyraRead (CIE), and (3) children's interaction with peers during the PyraRead activity (CIP). Each major behavior includes several specific behaviors, each labeled with a code.

Children's interaction with the content of PyraRead (CIC) encompassed behaviors such as reading words independently (c1), pointing at specific details in the animated 3D model (c2), and making comments related to the content, including its audio and sound effects (c3). Additionally, children were observed asking questions about the animated 3D model (c4), responding to or commenting on the content (c5), and either asking the teacher to repeat the content or verbally repeating the information themselves (c6).

Children's interaction with the 3D elements of PyraRead (CIE) involved pointing at the 3D features (c7), commenting on these elements (c8), asking related questions (c9), and providing responses based on the 3D visuals (c10). Some children also requested that the video be replayed to better view the 3D components, or they verbally repeated the information related to the 3D elements (c11).

Lastly, children were actively engaged in interactions with their peers during the PyraRead activity (CIP). These behaviors included making comments about the content to their peers (c12), asking peers questions about what they were viewing or learning (c13), responding to the content in peer discussions (c14), and repeating information shared by their peers (c15). These behaviors collectively reflect the dynamic and multifaceted ways preschoolers engaged with PyraRead, demonstrating active participation with the content, the holographic features, and their peers.

2.3 Research design

This study employs a quantitative approach using a quasi-experimental design. Over four weeks of experimentation, all participants were required to learn using the intervention tools: the 3D mobile PyraRead for the experimental group and the 2D mobile video for the control group. Each learning session was conducted for 30 minutes. The first week began with an achievement pre-test, followed by the first learning topic on alphabet spelling. The next three weeks continued with the following topics: recognizing syllables (rhymes), reading short sentences consisting of high-frequency words, and reading simple phrases composed of combinations of nouns and adjectives. In the fourth week, all research participants were given the achievement post-test. The detailed experimental procedure is depicted in Figure 1.

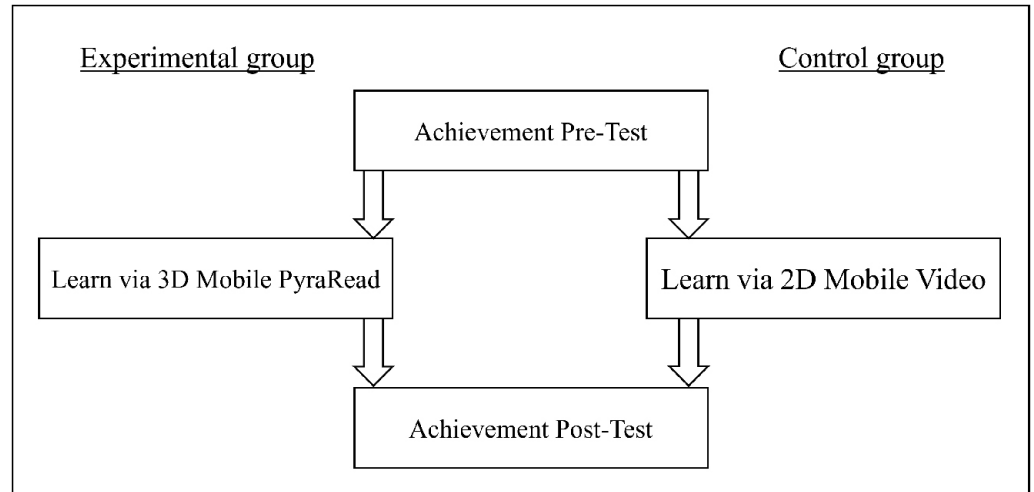


Fig. 1. Experimental procedure

2.4 Data analysis

Firstly, to assess preschool children’s achievement in English learning, pre-test and post-test assessments were conducted to examine the effects of the mobile PyraRead application on their improvement. The data from both tests were analyzed using the Statistical Package for the Social Sciences (SPSS), version 26. Both descriptive statistics (mean and standard deviation of pre-test and post-test scores for both groups) and inferential analyses were performed. Although more advanced modeling techniques such as regression analysis or ANCOVA could provide deeper insights, these were not feasible due to the small sample size and non-normal data distribution. A normality test conducted on the entire dataset revealed that the data did not meet the assumptions of normality (refer to Tables 2 and 3). Consequently, non-parametric tests were employed. Given the relatively small sample size ($n = 50$) and the characteristics of preschool data, which often violate normality and homogeneity of variance assumptions required for parametric tests, non-parametric approaches such as the Wilcoxon signed-rank test and Mann–Whitney U test were considered most appropriate. This approach is supported by Fagerland [36], who emphasized that non-parametric tests are particularly robust and suitable for small samples and non-normal datasets, especially in educational and behavioral research contexts. To enhance the interpretability of findings, effect sizes and 95% confidence intervals were also reported alongside p-values.

Table 2. Normality test for pre- and post-test of experimental group

Experimental Group	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-Test Marks	0.197	25	0.013	92.00	25	0.020
Post-Test Marks	0.220	25	0.003	85.04	25	0.005

Based on Table 3, the significance values ($p < 0.05$), which were 0.02 for the pre-test and 0.005 for the post-test, indicate that the data are not normally distributed.

Therefore, the non-parametric Wilcoxon test was used to identify the significant difference between the mean pre- and post-test scores for the experimental group.

Table 3. Normality test for pre- and post-test of control group

Control Group	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-Test Marks	0.132	25	0.020	93.09	25	0.043
Post-Test Marks	0.151	25	0.016	94.05	25	0.017

Based on Tables 2 and 3, since the significance values (p) of the post-test scores for both groups were less than 0.05, the Mann–Whitney U test was conducted to determine the significant difference between the mean post-test scores of the experimental and control groups.

Next, the study investigated the children’s interactions during the mobile PyraRead learning sessions. This section just involved the experimental group. For this interaction, data were collected through observation and analyzed using content analysis. Specifically, 15 behaviors (c1–c15) were coded to identify dominant interaction patterns among the preschoolers during PyraRead activities. As listed in Table 2, the behaviors were summarized as follows: c1 (reading), c2 (pointing), c3 (commenting), c4 (questioning), c5 (responding), c6 (repeating), c7 (pointing - 3D), c8 (commenting - 3D), c9 (questioning - 3D), c10 (responding - 3D), c11 (repeating - 3D), c12 (commenting - peers), c13 (questioning - peers), c14 (responding - peers), and c15 (repeating - peers). To ensure reliability, inter-rater reliability was conducted in which two raters independently evaluated the children’s interactions based on the defined codes.

Finally, the relationship between preschool children’s achievement and their interactions during PyraRead activities was examined using Spearman’s correlation analysis after conducting normality tests for each sub-app’s interaction data. Specifically, all 15 behaviors (c1–c15) from each sub-app were tested against the children’s test results. The strength of the Spearman correlation coefficient (r) was interpreted according to Chua [37].

3 RESULTS

This study examined whether there was a significant difference in preschool children’s English literacy achievement between the experimental group, which used the 3D mobile PyraRead, and the control group, which used the 2D mobile video. Pre-test data were collected during the first week of the experiment for both groups. After completing the learning sessions with the 3D mobile PyraRead and the 2D mobile video, a post-test was administered to all participants. Children’s interactions with the four sub-apps were observed through video recordings, and content analysis was conducted with inter-rater reliability procedures.

3.1 Results of the achievement tests

Research Question 1 investigated the effects of the 3D mobile PyraRead on preschool children’s English literacy achievement compared to the 2D mobile video.

A descriptive analysis of the pre-test and post-test results was conducted. The mean scores and standard deviations for both the pre-test (N = 50) and post-test (N = 50) of the experimental and control groups were analyzed. Overall, all preschool children showed an increase in their post-test scores after learning through the 3D mobile PyraRead application. The minimum and maximum scores, along with the mean and standard deviation values for both the pre-test and post-test, are presented in Table 4.

Table 4. Descriptive analysis of pre- and post-test for experimental group and control group

Group	N	Pre-Test		Post-Test	
		Mean	Standard Deviation	Mean	Standard Deviation
Experimental	25	84.80	8.307	92.00	6.633
Control	25	81.36	9.251	85.04	7.530

By referring to Table 4, the mean score for the post-test (experimental group) shows a high score with 92 over 100, while the control group was 85.04 out of 100. Thus, from these values, we can conclude that all the preschool children (N = 25) in the experimental group show improvement in their post-test scores after they learn through 3D mobile PyraRead compared to 2D mobile video. In terms of standard deviation, the value for both the pre-test and post-test for the experimental group shows a lower value than the control group. As an interpretation, the lower value of standard deviation (experimental group) shows that the data are clustered closely around the mean, which is more reliable compared to the high standard deviation value (control group), where the data are widely spread (less reliable). Next, the inferential analysis of achievement tests among preschool children for both the experimental group and the control group will be analyzed.

Table 5. Inferential analysis of achievement test for experimental group and control group

	Group	N	Mean Rank	Mann-Whitney U	Z	Asymp. Sig. (2-tailed)
Pre-test Score	Experimental	25	28.84	229.00	-1.628	0.104
	Control	25	22.16			
	Total	50				
Post-test Score	Experimental	25	32.04	149.00	-3.191	0.001
	Control	25	18.96			
	Total	50				

Since the normality test indicated that the achievement data for both the experimental and control groups were not normally distributed, a non-parametric test, specifically the Mann-Whitney U test, was chosen to analyze the data. The Mann-Whitney U test compares the number of times a score from one sample is ranked higher than a score from another sample. Based on the pre-test score data in Table 5, the mean rank value for the experimental group (mean rank = 28.84) was slightly higher than that of the control group (mean rank = 22.16). Moreover, the p-value of 0.104 (> 0.05) indicates that the existing knowledge of the children in both groups

was approximately the same before the intervention. However, for the post-test scores, the mean rank for the experimental group (mean rank = 32.04) was higher than that of the control group (mean rank = 18.96). It is important to note that the p-value of 0.001 (< 0.05) with a Z value of -3.191 indicates a statistically significant difference in achievement between the experimental and control groups.

3.2 Result of the children's interactions

Based on the checklist by Cheng and Tsai [30], three major behaviors and 15 specific behaviors were adapted to suit the 3D mobile PyraRead activity. The entire dataset was analyzed and categorized according to children's interactions with PyraRead (c1 to c11) and children's interactions with peers (c12 to c15). Overall, based on the sub-applications of PyraRead, Sub-App 1 recorded the highest number of interactions (1,159), followed by Sub-App 2 (1,123) and Sub-App 4 (1,122). Sub-App 3 showed the lowest number of interactions, with a total of 1,038.

In terms of interactions with PyraRead, across all sub-applications, two specific behaviors were observed most frequently. These behaviors fell under the major category of Children's Interaction with the Content of PyraRead (CIC). The most common behaviors were 'responding' (c5) and 'repeating' (c6). In terms of peer interactions across all PyraRead modules, the specific behavior with the highest frequency was 'responding' (c14), where children responded to the content of PyraRead with their group peers. However, the total number of peer interaction behaviors (CIP) was less prominent compared to children's interactions with the content of PyraRead (CIC) and their interactions with the AR elements (CIE). Therefore, children's interactions can be summarized based on the frequency of specific behaviors observed during the learning sessions with PyraRead, arranged in descending order for each module. The data are presented in Table 6.

Table 6. Children's interactions based on specific behaviors

Interactions Sub-Apps	Interactions with PyraRead		Interactions with Peers	
	High	Low	High	Low
Sub-App 1	c5, c6	c4, c11	c14, c12	c15, c13
Sub-App 2	c5, c6	c7, c11	c14, c15	c12, c13
Sub-App 3	c6, c5	c7, c11	c14, c13	c12, c15
Sub-App 4	c5, c6	c7, c11	c14, c12	c13, c15

3.3 Result of the relationship between preschool children's achievement and interactions

Next, to answer Research Question 3 regarding the relationship between preschool children's achievement and their interactions while using the 3D mobile PyraRead to improve their English literacy, Spearman correlation analysis was employed, as the data for all PyraRead sub-apps were not normally distributed. The findings from this analysis are presented in Table 7. This study examined two types of children's interactions: interactions with the learning tool (PyraRead) and interactions with peers during the PyraRead activity.

Table 7. Correlations for children's interactions and achievement

Spearman Correlation Coefficient (<i>r</i>)				
Sub-Apps/Behaviors	Sub-App 1	Sub-App 2	Sub-App 3	Sub-App 4
Interactions towards PyraRead				
c1	.657**	.713**	.355	.115
c2	-.372	-.348	-.320	-.339
c3	.445*	.477*	.135	.302
c4	.641**	.688**	.376*	.426*
c5	.541**	.565**	.339*	.197
c6	.491*	.559**	.382	.080
c7	-.022	-.081	-.284	-.051
c8	.337	.555*	.152	.130
c9	.545**	.543*	.453*	.434*
c10	.292	.387	.074	.375
c11	.633**	.352	-.013	.378
Interactions with Peers				
c12	.265	.385	-.032	.407*
c13	.560**	.544**	.423*	.313
c14	.365	.737**	.386	.463*
c15	-.545	-.663**	-.200	-.532*

According to Table 7, the most consistent pattern emerging across all sub-apps is the strong and repeated correlation between children's questioning behaviors and their literacy achievement. Specifically, c4 (questioning the PyraRead content) and c9 (questioning the 3D elements) demonstrated significant relationships in every sub-app. This indicates that PyraRead stimulates children's curiosity and encourages them to ask questions, which reflects deeper cognitive engagement. Questioning is widely recognized as a higher-level interaction behavior, signaling active meaning-making rather than passive observation, which explains its consistent association with improved literacy outcomes.

Beyond questioning, response-related behaviors also contributed meaningfully to children's achievement. Behaviors such as responding to the holographic content (c5) and responding to peers (c14) were frequently associated with higher literacy scores across multiple sub-apps. These behaviors suggest that when children verbally process what they see, either by interacting with the content or engaging in dialogue with peers, they reinforce their understanding and strengthen their internalization of new vocabulary and literacy concepts.

Peer-mediated engagement further supports learning. Behaviors such as questioning peers (c13) and repeating peers' statements (c15) were among the strongest peer interactions linked to achievement, particularly in modules containing more complex literacy content. These behaviors illustrate how collaborative meaning-making, negotiation of ideas, and shared verbal rehearsal contribute to children's comprehension and vocabulary development.

Overall, the findings show that not all interactions contribute equally. The strongest predictors of literacy achievement were questioning behaviors and verbal response behaviors. These types of interactions require children to process information, articulate their understanding, and construct meaning actively. Such behaviors align closely with established principles of early literacy development and provide a clear explanation for why children who displayed them tended to achieve higher post-test scores.

4 DISCUSSION

The main purpose of this study was to examine the effectiveness of the 3D mobile PyraRead application compared to a 2D mobile video in enhancing preschool children's English literacy, as well as to explore children's interactions and the relationship between their interactions and achievement. Overall, the findings provide preliminary but valuable evidence on the potential of mobile-based 3D pyramid holograms in early literacy learning.

4.1 Research Question 1

The results demonstrated that children who learned using the 3D mobile PyraRead showed significantly higher post-test scores than those using the 2D mobile video. This suggests that the reflective hologram technology, particularly the illusion of animated objects "floating" in mid-air, may help young learners focus on salient features, thereby improving comprehension and vocabulary recognition.

A notable observation in this study was the high pre-test scores for both groups, likely due to children's prior exposure to similar content in their first year of preschool. This situation introduces a ceiling effect, in which limited room for improvement restricts the magnitude of observable learning gains. Although the experimental group still showed greater improvement (mean gain = 7.2 points) than the control group (mean gain = 3.7 points), these gains should be interpreted as relative rather than absolute improvements. This limitation is common in quasi-experimental designs involving young learners, where prior knowledge is not fully controllable, a point consistent with Sailer and Homner [38]. Nevertheless, the improvements shown by the experimental group indicate that PyraRead may strengthen literacy even for children who already demonstrate baseline proficiency. Future studies should include children with more varied literacy levels to determine whether 3DPH technologies benefit struggling learners as effectively as high-performing ones. Hence, the difference between pre-test and post-test scores does not directly affect the measured effectiveness of PyraRead.

According to An et al. [39], the use of mobile holographic video displays plays a crucial role in content delivery, as their interactive 3D interfaces encourage viewers to focus on the projected object rather than the device screen. This feature can enhance learners' understanding of the subject. In the context of this study, PyraRead effectively improved children's understanding of English literacy compared to the 2D mobile video. This finding aligns with studies showing that 3D pyramid holograms enhance children's language learning by providing clearer representations of learning objects [40].

This conclusion is further supported by Wei et al. [41], who found that 3D VR tools were effective for improving reading comprehension compared to traditional

2D figures. Furthermore, the animated 3D models used throughout the PyraRead modules contributed to a gradual improvement in children's English vocabulary. This finding is consistent with the study by Du et al. [42], who highlighted that 3D technologies such as AR can offer more interactive and immersive reading experiences, making AR a promising tool for supporting literacy development among young learners. These international findings reinforce the present results and suggest that the advantages of PyraRead extend beyond novelty or visual appeal. Although the sample was limited to Malaysian preschool children, the findings align with international studies that highlight the benefits of immersive and interactive 3D technologies for early literacy skills development [43]. Importantly, this study contributes uniquely by examining *mobile-based* 3D pyramid holograms, which require only a tablet and a low-cost pyramid prism, thus making the approach feasible across diverse and resource-limited educational settings.

4.2 Research Question 2

The observation data showed that children demonstrated positive interactions across all sub-applications of the 3D mobile PyraRead, as reflected in the 15 specific behaviors measured. However, interaction levels tended to decrease when the learning content became more difficult. This pattern is expected, as preschool curricula typically progress from simple to more complex topics toward the end of the academic year. Soviany et al. [44] emphasized that meaningful learning occurs when learners are gradually introduced to increasingly challenging content, which may explain the reduction in observable interactions during the later PyraRead modules.

Overall, the children's interactions with both the PyraRead tool and their peers indicated strong engagement throughout the learning process. Previous studies have similarly noted that 3D mobile holographic displays, as immersive and interactive learning tools, can enhance students' attention to learning materials and increase their motivation to engage with the content and their peers [45], [46]. This aligns with the findings of Dalim et al. [47], who reported that 3D AR applications improved children's English vocabulary acquisition and enabled them to complete learning tasks more efficiently compared to traditional teaching methods.

In the context of this study, the enjoyable and visually stimulating 3D elements of PyraRead appeared to sustain children's interest, encouraging continuous exploration and active participation. The immersive qualities of the 3DPH format support children's natural inclination toward play-based learning and discovery, which are central to early childhood pedagogy. Thus, the present findings further demonstrate that mobile-based 3D holographic tools can effectively promote engagement and interactive learning among preschoolers, particularly in literacy-related tasks.

4.3 Research Question 3

For Research Question 3, the Spearman correlation analysis was conducted to examine the relationship between children's interaction behaviors and their English literacy achievement when using the 3D mobile PyraRead. The results revealed that 12 out of the 15 specific interaction behaviors were positively associated with children's post-test scores, suggesting that richer interaction corresponds to better literacy performance. This finding aligns with the claim that the depth and quality of student interaction enhance cognitive processing and understanding [48].

A particularly meaningful pattern emerged from the data: the behaviors related to questioning demonstrated the strongest and most consistent correlations. Behaviors such as questioning the content (c4) and questioning the 3D images (c9) showed clear associations with literacy achievement. This suggests that PyraRead may stimulate children's curiosity, encouraging them to seek clarification and actively process the learning materials. Such questioning behaviors reflect deeper levels of cognitive engagement and have been emphasized in prior hologram-based and mobile-assisted language learning studies [49].

Similarly, the specific peer interaction behaviors (c12, c13, c14, and c15) also showed positive correlations with achievement. According to Czeszumski et al. [50], cooperative peer interactions support more complex forms of social engagement that directly contribute to comprehension. When preschool children collaborate, they share insights, negotiate meanings, and clarify misunderstandings, all of which facilitate conceptual understanding. As Huang et al. [51] observed, positive peer engagement fosters deeper learning and improves both social interaction and academic achievement.

The results also align with broader international studies emphasizing the role of peer interaction in literacy development. Structured peer exchanges during shared reading activities allow children to co-construct meaning, reinforce vocabulary, and strengthen discourse skills in learning English [52], [53]. Mitsven et al. [54] further reported that interaction with high-engagement peers increases conversational turns and phonemic variety, which are key components of early language development.

Taken together, the findings suggest that the effectiveness of PyraRead may not lie solely in its 3D holographic visualization but also in the way it naturally promotes verbal, cognitive, and social interaction among young learners. These multi-dimensional interactions appear to work synergistically to reinforce literacy learning, supporting the idea that mobile-based 3D holograms can serve as powerful tools for early language education.

5 LIMITATIONS AND FUTURE RESEARCH

This study has several limitations that should be acknowledged. First, although it provides meaningful insights, its findings should be interpreted with caution due to the narrow geographic scope (two preschools within one Malaysian district) and relatively small sample size ($N = 50$). These constraints limit the generalizability of the results beyond the immediate context. In addition, both groups demonstrated high pre-test scores, indicating substantial prior knowledge and suggesting the presence of a ceiling effect. This limits the magnitude of observable learning gains and restricts the ability to determine whether the 3D mobile PyraRead would be equally beneficial for children with lower proficiency levels. Nevertheless, the study should be regarded as a pilot investigation that offers early evidence on the use of mobile-based 3D holographic tools for preschool literacy. Future studies are encouraged to expand the sample to include diverse regions and cultural contexts, as well as children with varying levels of literacy proficiency, to validate and extend the present findings.

Second, the study duration covered only four weeks. Although all syllabus topics were introduced through PyraRead, several were covered only briefly. Longer-term studies, ideally six months or a full academic year, would enable children to engage more deeply with the content and provide stronger evidence regarding sustained learning outcomes and retention. Extended intervention periods would

also allow researchers to examine developmental progress across different stages of early literacy.

Third, the application used uniform scene transition timings across all modules, regardless of topic complexity. This design choice may have influenced children's engagement and response behaviors, particularly in more challenging modules. Future iterations of PyraRead should consider integrating adaptive transition durations that correspond to task difficulty, allowing children adequate processing time and supporting more meaningful interaction.

Lastly, while the use of non-parametric tests was appropriate given the modest sample size and non-normal data distribution, more advanced statistical techniques could not be applied. Future research with larger samples could employ analytical methods such as ANCOVA, regression modelling, or longitudinal analyses to provide deeper insights into the effects of mobile-based 3D holographic learning tools. Collectively, these limitations highlight the need for future research involving larger and more diverse samples, longer study durations, adaptive system features, and more robust statistical approaches to strengthen the evidence base and further explore the educational potential of 3D hologram-assisted learning.

6 IMPLICATIONS

The outcomes of this study offer important theoretical, practical, and policy implications. Theoretically, the findings reinforce global frameworks such as Piaget's Theory of Cognitive Development, the NCCA's Characteristics of Play, and Mayer's Cognitive Theory of Multimedia Learning, all of which emphasize active engagement, sensory-rich inputs, and play-based exploration for deeper learning. The 3D mobile holographic design of PyraRead enables preschool children to construct knowledge through interactive exploration while simultaneously processing visual, auditory, and kinesthetic cues. This illustrates how holographic technologies, positioned between augmented and mixed reality, can create immersive learning environments that support attention, cognitive processing, and early literacy development. These principles are not limited to Malaysia but align with widely accepted pedagogical foundations used internationally.

Practically, integrating reflective holographic tools such as PyraRead into preschool classrooms can enrich literacy instruction by fostering deeper interaction, sustained engagement, and active participation, particularly in subjects requiring frequent reinforcement, such as English literacy. The tool's interactive nature also offers potential benefits for learners who struggle with traditional instructional methods, making classroom environments more inclusive and adaptable to diverse learning profiles. For curriculum designers, the study highlights the importance of embedding immersive and child-centered features into early childhood curricula. For educational technology developers, the findings underscore the need to design hologram-based applications with adaptive pacing and developmentally appropriate interactions that can be transferred across different cultural and linguistic contexts.

At the policy level, the study suggests how ministries of education and early childhood institutions might explore the scalable use of low-cost immersive technologies to complement conventional pedagogy. Unlike many AR/VR systems requiring specialized hardware, PyraRead relies only on a mobile device and an inexpensive pyramid prism, making it feasible for broader adoption, including resource-constrained settings. Although preliminary, this work represents one of the earliest examinations of mobile-based 3D holographic tools for preschool literacy and provides

a foundation for future cross-country, longitudinal, and large-scale research. Collectively, these implications highlight the potential of holographic technologies to create more engaging, inclusive, and future-ready learning environments for young children worldwide.

7 CONCLUSIONS

This study investigated the effectiveness of the 3D mobile holographic application PyraRead in enhancing preschool children's English literacy, focusing on both academic achievement and interaction behaviors during classroom learning. The findings showed that 12 of the 15 observed behaviors were positively associated with literacy outcomes, indicating that meaningful engagement with the 3D holographic content supported better post-test performance and improved English literacy understanding. These results suggest that PyraRead can facilitate interactive, immersive, and cognitively stimulating learning experiences for young children.

While the study was conducted with a modest and geographically specific sample, it offers important early evidence on the potential of mobile-based 3D holographic tools in preschool literacy instruction. The findings contribute to the growing body of research on low-cost, scalable immersive technologies and hold relevance not only for Malaysia but also for international early childhood settings seeking innovative approaches to foundational literacy skills.

Future studies could extend this work by examining longer-term learning effects, implementing the intervention across more diverse populations, and exploring the use of holographic applications in other subject areas. Such research would strengthen the generalizability of the current findings and further illuminate the role of holographic technologies in supporting young children's learning and development.

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9 ETHICAL COMPLIANCE

This study received ethical approval from the Ministry of Education, Malaysia [Ref. No.: KPM.600-3/2/3-eras (4505)], in accordance with ethical guidelines for research involving government preschool participants. All necessary permissions were obtained, including from the Johor State Education Department, the school principals, the assistant principals for student affairs, and the preschool teachers. All participants were informed of the purpose of their participation throughout the study.

Moreover, to ensure academic integrity, no generative AI tools were used in preparing this manuscript, including drafting and analysis. All content, analysis, and revisions were conducted manually and are entirely the author's own work based on the study.

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